SATCOM

QUARTERLY

Mobile • • • Micro • • • Personal

Jet Propulsion Laboratory No. 8 January 1993

IMSC '93 to be Held in June

The Third International Mobile Satellite Conference (IMSC '93) will be held June 16–18, 1993, at the Pasadena Convention Center in Pasadena, California. IMSC '93 is cosponsored by NASA/JPL and the Department of Communications, Canada/Communications Research Centre.

The initial response to the Conference announcement has been excellent. More than 500 people are expected to attend and more than 100 papers have been selected for presentation.

The Conference theme this year will reflect the increasing interest in personal communications and the interconnection of terrestrial and satellite communications. Scheduled sessions are:

- Advanced System Concepts and Analysis
- Hybrid Networks for Personal and Mobile Satellite Applications
- Regulatory and Policy Matters
- User Requirements and Applications
- Propagation
- Current and Planned Systems
- Spacecraft Technology
- Mobile Terminal Technologies
- Mobile Terminal Antenna Technologies
- Direct Broadcast Satellite/Audio
- Modulation, Coding and Multiple Access Techniques

A special event being planned is a panel discussion comparing low-Earth-orbit satellite systems to geosynchronous-Earth-orbit systems. Top-level representatives from the principal service providers are being invited to participate on the panel.

Another major attraction at the Conference will be an International Mobile Satellite Exhibition, in which organizations from around the world will provide information about their mobile satellite products and services and offer demonstrations.

A NASA Propagation Experiments (NAPEX) meeting will be held at the Pasadena Hilton Hotel June 14–15, immediately preceding IMSC '93. For more information on the NAPEX meeting, please contact Mardy Wilkins at (818) 354-1723; fax (818) 393-0096.

Individuals or companies wishing to attend or participate as exhibitors at IMSC '93 should contact the Organizing Committee at JPL as soon as possible. Preregistration is strongly encouraged as space is limited.

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The Satellite Communications (SATCOM) Program is managed by the Jet Propulsion Laboratory for the National Aeronautics and Space Administration. The goals of this Program are to develop advanced system concepts and technologies in the areas of mobile, micro and personal communications. A major thrust of the Program through the mid-1990s is the development of the mobile terminal to operate with NASA's Advanced Communications Technology Satellite.

The JPL Ka-Band Propagation Measurements Campaign

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The objective of the JPL Propagation Program is to enable new SATCOM applications and enhance existing space services. This is accomplished by such activities as conducting field measurements, developing predictive models for propagation effects, participating in regulatory groups and disseminating information. Although the project is managed at JPL, most of the experimental work is conducted at universities.

Telecommunications via satellites began commercial use at C-band (4/6 GHz). The limited allocation (500 MHz) in C-band was soon congested, and in the 1980s, the higher frequency Ku-band (12/14 GHz) was introduced specifically in the domestic SATCOM arena. However, the bandwidth allocation (500 MHz) in this band is also becoming saturated. This has led to the investigation of using the next higher frequency region, Ka-band (20/30 GHz), for satellite communications. The 1000+ MHz available in this band is attractive for satellite communications. However, the short wavelengths in this band become susceptible to the perturbing elements affecting space-to-Earth propagation shown in Table 1.

Rain attenuation depends on rain rate, rain pathlength and drop size distributions. At Ka-band (1.0–1.5-cm wavelength), raindrop size is comparable to wavelength and attenuation is so severe that in some cases it becomes too costly to provide compensation. As a result, communication link outage is inevitable.

The Advanced Communications Technology Satellite (ACTS) is NASA's latest experimental communications spacecraft. The quality of data from the ACTS experiments will depend on how accurately the rain fade statistics and fade dynamics can be measured in order to derive an appropriate algorithm to combat fading — specifically for links with small terminals, such as very small aperture terminals, where the power margin is at a premium. Preparations for ACTS propagation experiments began in 1988 when it was decided to take propagation measurements using the European Space Agency (ESA) Olympus satellite as a precursor. The experience gained with Olympus has been invaluable in preparing for the ACTS experiments and has also resulted in a useful database of 20- and 30-GHz propagation data.

This article reviews the Olympus program data collected to date [1] and the planning process, hardware development and measurement program involved in the forthcoming ACTS propagation experiments.

The Olympus Experiment

ESA launched the Olympus satellite in July 1989. Olympus has frequency-coherent propagation beacons at 12.5, 19.77 and 29.66 GHz. Under JPL sponsorship, Virginia Polytechnic Institute (Virginia Tech) constructed four Earth terminals to receive each of the three beacon frequencies, plus a second 20-GHz terminal for short-baseline diversity measurements. There are also radiometers at each frequency. The beacons are visible from Blacksburg, Virginia, at a 14-deg elevation angle. This corresponds to the lowest elevation angle in the continental United States (CONUS) when using domestic satellites, making resulting data a lower performance limit case. A unique feature of this experiment is the simultaneous satellite reception of signals spanning Ku-band through Ka-band from the same orbital slot, which permits direct frequency scaling. An additional advantage is that the 12-GHz coherent beacon, which is subjected to less attenuation than 20/30-GHz beacon attenuation, permits receiver lock for the 20/30 channels during heavy fades.

Element	Effect	Remedy
Gaseous attenuation	Noticeable	Built-in margin
Hydrometeor attenuation		
Cloud	Measurable	Built-in margin
Rain	Severe	Adaptive compensation
Snow	Measurable	Can be circumvented
Fog	Negligible	—
Depolarization	Complex	Can be compensated
Scintillation	Rapid fluctuation of signal; dependent on site, time of day and season	Not easy to circumvent
Excess noise emission	Signal absorption gives rise to broadband noise emission	Can be circumvented by additional system margin

Table 1. Perturbing elements affecting space-to-Earth wave propagation.

After hardware development and calibration, propagation measurements began in August 1990. The Olympus spacecraft developed a problem during the period from the end of May 1991 through the middle of August 1991; however, approximately 10 months worth of uninterrupted data were collected during the first year of the data collection program. The first-year data collection and analysis reports have been published [2,3], and the second-year data collection program has recently been completed.

The Olympus experiment system at Virginia Tech is shown in Figure 1. The terminal power budget is shown in Table 2.

Samples of the following data are shown in Figures 2–6 and in Table 3:

- Sky brightness temperature and time series of signal attenuation.
- Attenuation statistics.
- Beacon attenuation compared with radiometer data.
- Measured fade and fade slope.
- Microdiversity.
- Scintillation spectral analysis.
- Attenuation ratios.

Sky brightness temperature increase and signal attenuation plots at 20 GHz on May 12, 1991, are shown in Figure 2. Attenuation statistics for three frequencies for May 1991 are shown in Figure 3.

A comparison of beacon attenuation and radiometrically derived attenuation statistics at 12 GHz for the month of May 1991 is shown in Figure 4. A measured fade on May 6, 1991, and the corresponding fade slope at 20 GHz are shown in Figure 5. The 30-GHz beacon scintillation spectral analysis is shown in Figure 6 for an active and a quiet day during the first year of data collection.

The statistics of attenuation ratios at 20 and 30 GHz for the month of May 1991 are shown in Table 3.

The ACTS Propagation Program

The purpose of ACTS is to demonstrate the feasibility of Ka-band for satellite communications, as well as to help maintain the leadership of the United States in satellite communications. ACTS incorporates such innovative schemes as TDMA; microwave and baseband switching; onboard regeneration, and adaptive application of coding during rain fade conditions.

A plan for the ACTS propagation terminal was initiated at the first ACTS Propagation Studies Workshop held November 28–29, 1989 [4]. The group addressed a number of topics, including the need for propagation data and the configuration and number of propagation terminals required to gather these data. Participants delivered a set of recommendations regarding propagation studies

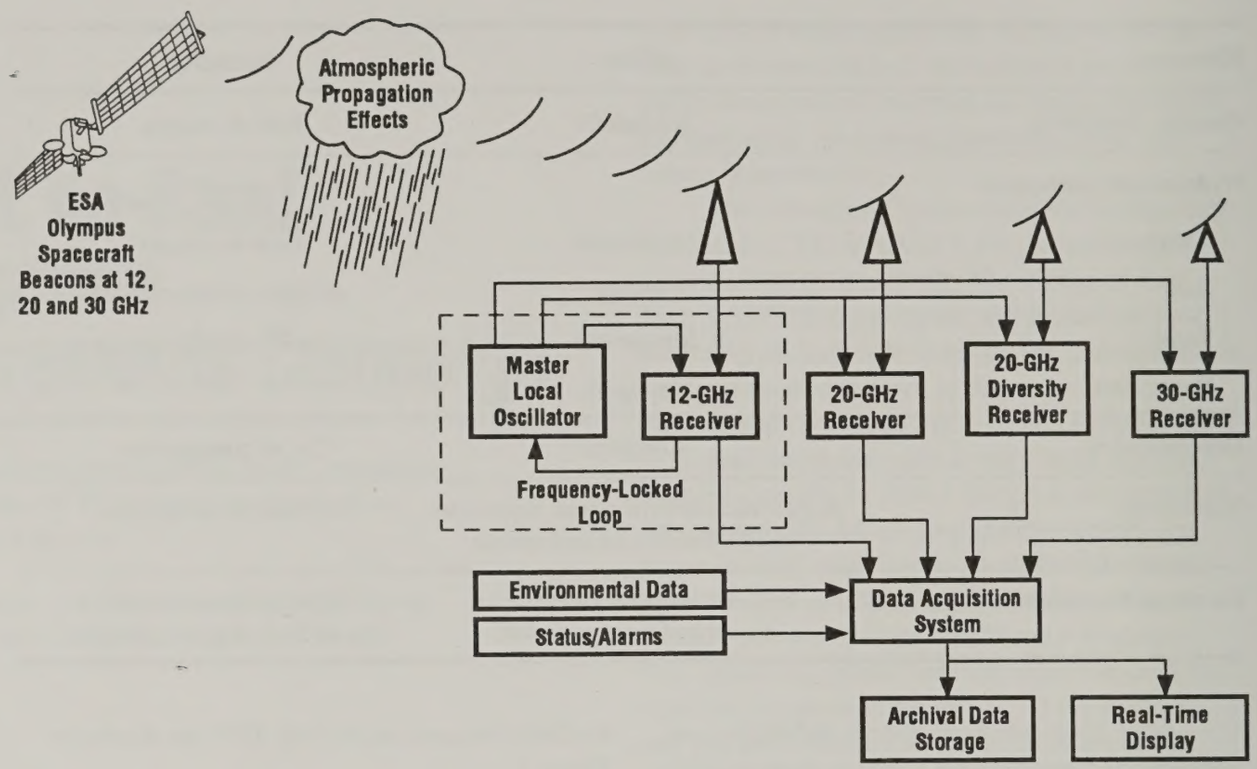

Figure 1. Olympus experiment system at Virginia Tech.

Table 2. Terminal power budget for the Olympus experiment.

Parameter	Terminal		
	12 GHz	20/20D* GHz	30 GHz
Frequency, GHz	12.502	19.77	29.66
Linear polarization	Y	Switched X, Y	Y
Maximum EIRP, dBW	13.1	31.7	27.7
Pointing loss to Blacksburg, dB	4.0	10.0	10.0
Path loss, dB	207.0	211.0	214.5
Clear-sky attenuation, dB	0.25	1.0	0.8
Antenna diameter, m	3.7	1.5	1.2
Antenna gain, dB	51.4	47.3	49.0
Pointing loss, dB	0.3	0.1	0.2
Switching loss, dB	0.0	6.0	0.0
System noise temperature, K	448.3	692.0	1,029.5
C/N in 3 Hz, dB	50.3	46.4	44.9

** "D" refers to the second 20-GHz terminal, used for diversity measurements.*

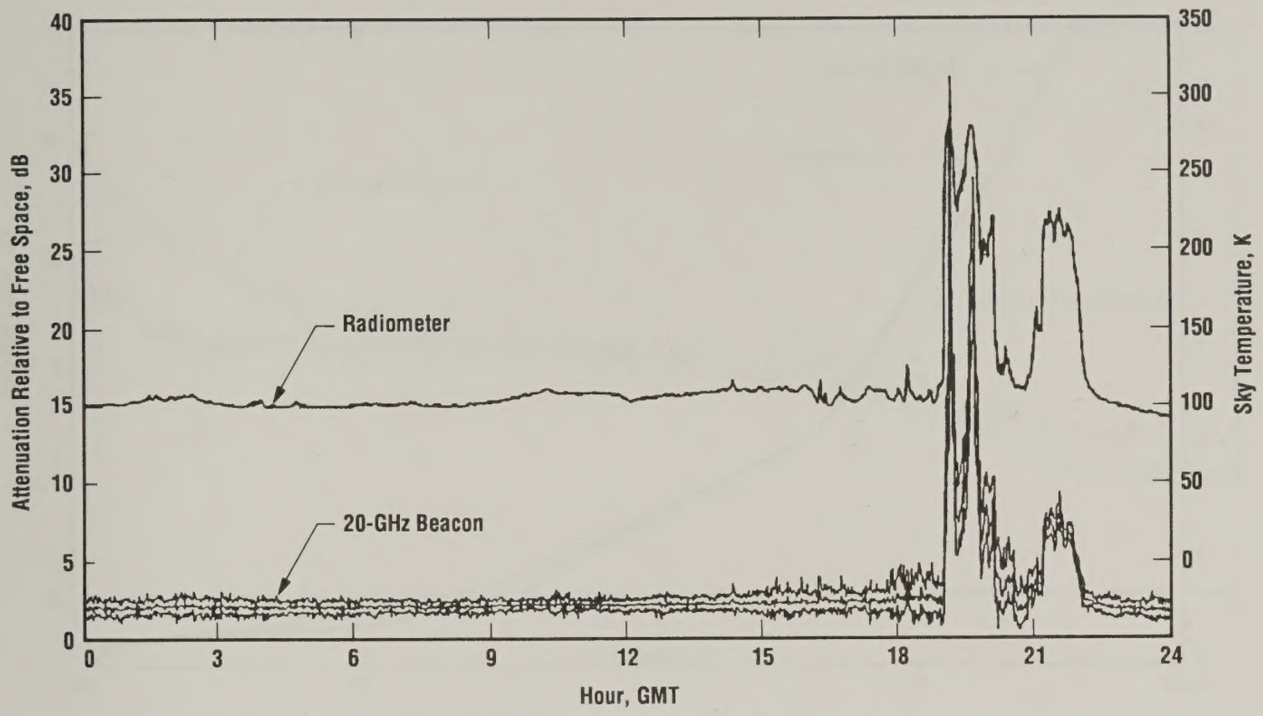

Figure 2. Propagation data, 20-GHz beacon, May 12, 1991.

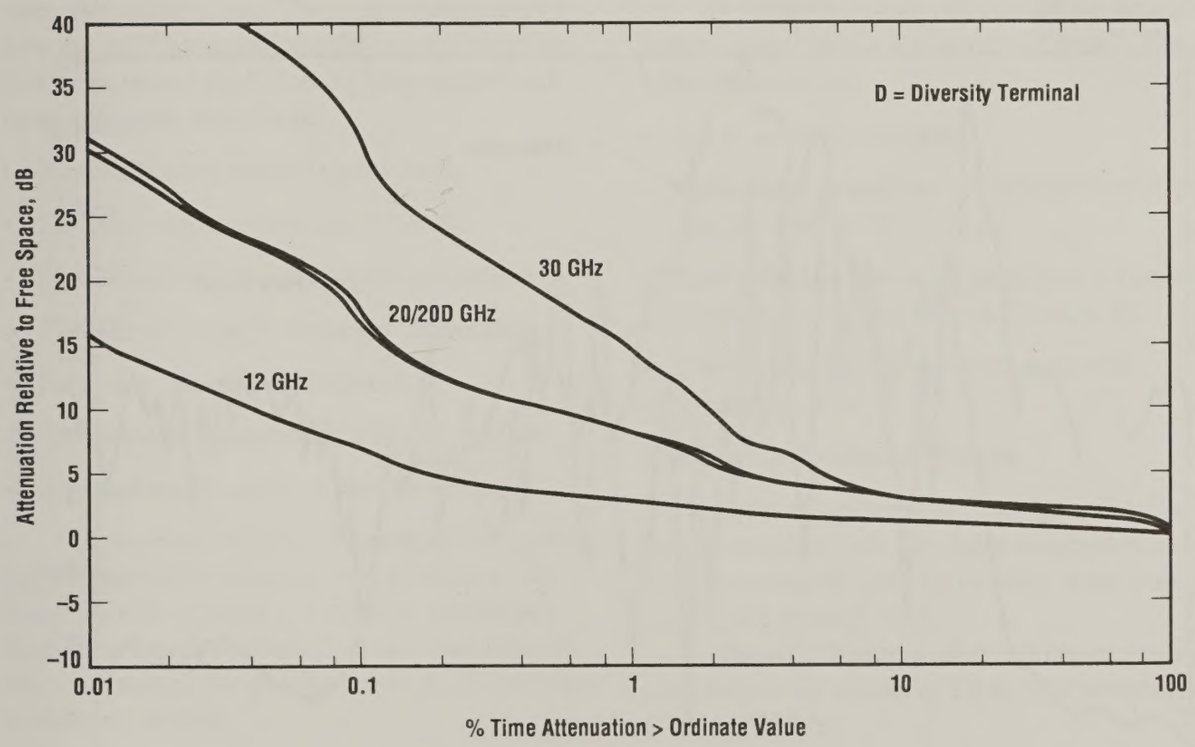

Figure 3. Attenuation statistics for three frequencies, May 1991.

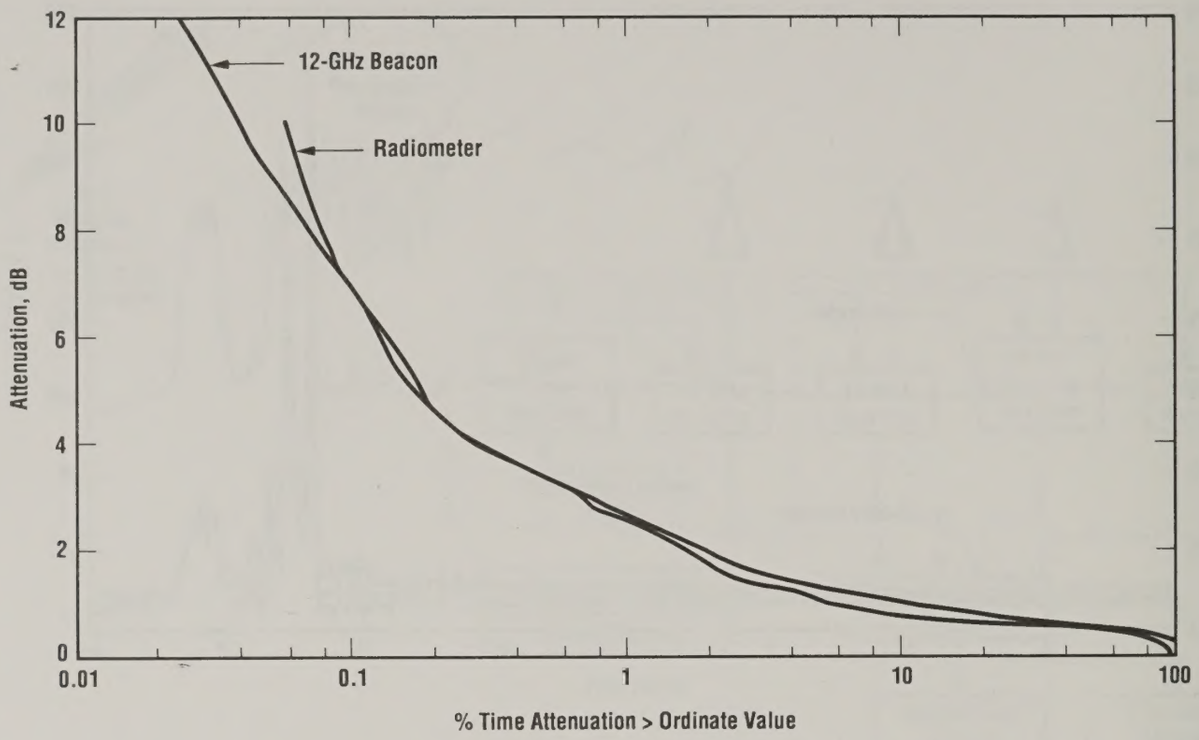

Figure 4. Comparison of 12-GHz beacon attenuation and radiometrically derived attenuation, May 1991.

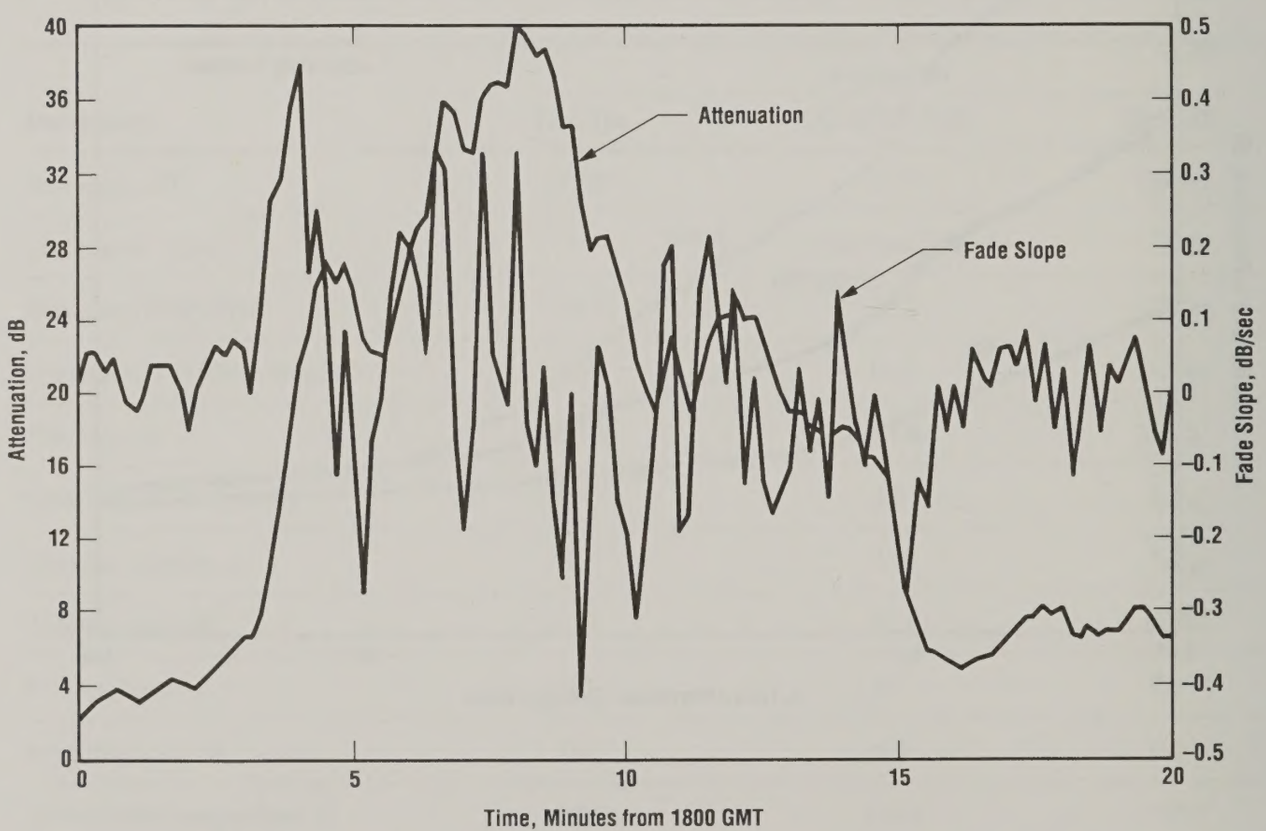

Figure 5. Measured fade and corresponding fade slope, 20-GHz beacon, 10-sec block average, May 6, 1991.

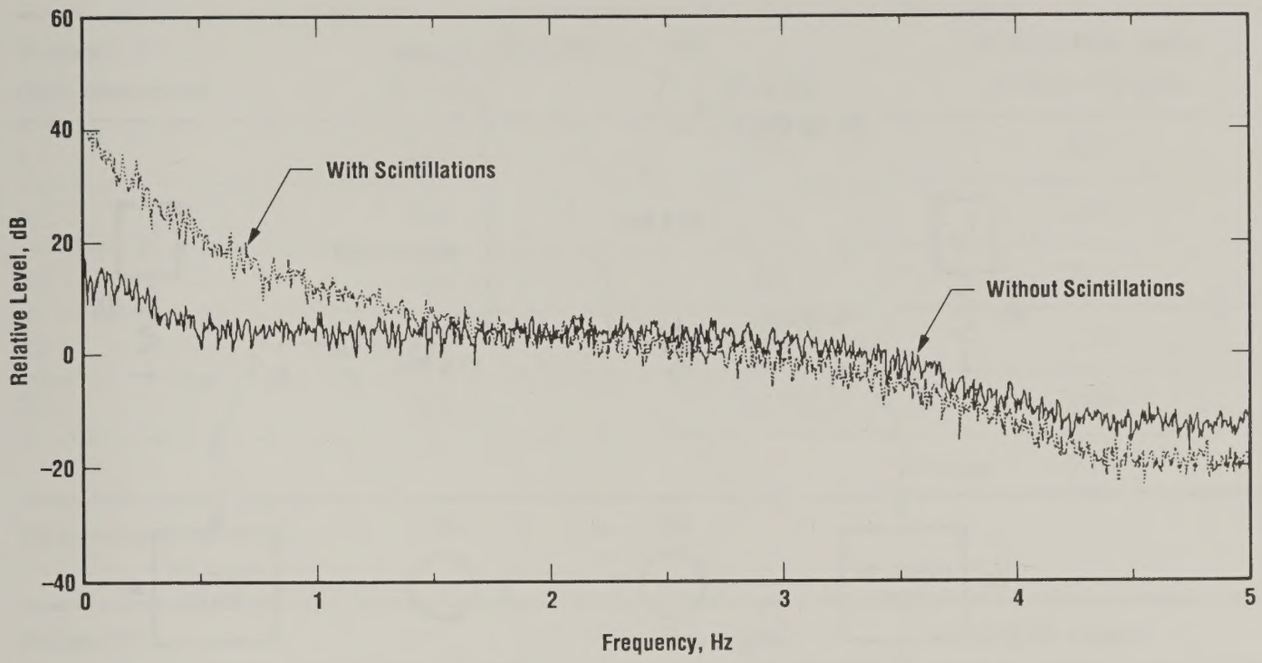

Figure 6. Scintillation spectral analysis, 30-GHz beacon, for an active day (August 26, 1990) and a quiet day (December 1, 1990).

and experiments that would use ACTS. They also provided guidelines regarding measurement parameters and requirements. These guidelines specify how the ACTS terminal should be configured so that it can record the following propagation and meteorological parameters:

- 20-GHz beacon receive signal level.
- 27-GHz beacon receive signal level.
- 20-GHz radiometric sky noise temperature.
- 27-GHz radiometric sky noise temperature.
- Point rain rate near the terminal.
- Atmospheric temperature at Earth's surface.
- Atmospheric humidity at Earth's surface.

In response to the recommendations concerning propagation terminals, a two-phase plan has been devised. In phase 1, a terminal prototype is being developed; in phase 2, seven terminals will be manufactured for distribution to ACTS propagation experimenters.

Development of a Prototype Receive Terminal

A NASA research grant was awarded to Virginia Tech early in 1991 for development of a prototype receive terminal. The terminal will consist of a common antenna, a dual-channel digital receiver, a dual-channel analog radiometer and a data acquisition system. It will also be equipped with meteorological recorders for measuring the point rain rate and the atmospheric temperature and humidity.

A simplified block diagram of the propagation receive terminal is shown in Figure 7. The salient features are:

- 1.2-m common antenna.
- Orthomode transducer (OMT)/diplexer to separate 20- and 30-GHz signals.
- Cost-effective low-noise amplifiers followed by single downconversion to a 70-MHz IF.
- Total power radiometer with detectable sensitivity of ±1 K.
- PC/AT-based data collection.

The receiver terminal's design will be based upon a modular form for easier integration and testing. The schedule calls for delivery at the time of launch in February 1993.

The ACTS propagation receive terminal link calculations are shown in Table 4 for worst-case C/N in CONUS.

Conclusion

The Olympus measurements carried out at Virginia Tech and many European sites acted as a testbed for resolving technical, data collection and analysis problems. The Olympus experiment will thus benefit the forthcoming ACTS propagation measurements, for which NASA is funding seven

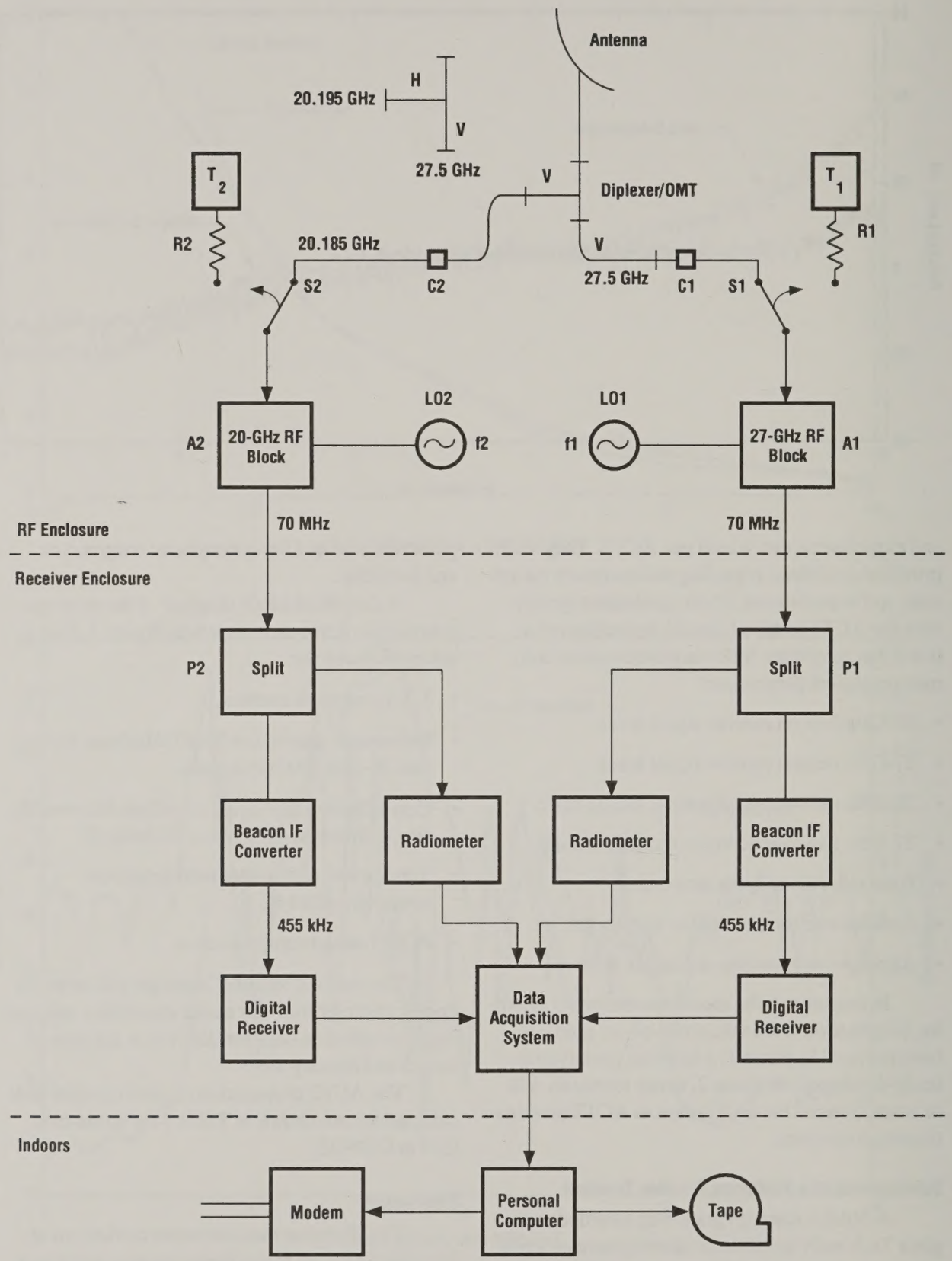

Figure 7. ACTS propagation receive terminal diagram.

Percent of time exceeded	Attenuation,* dB		Attenuation ratio,
	30 GHz	20 GHz	30 GHz/20 GHz
1	12.4	5.9	2.11
0.5	16.4	7.6	2.15
0.3	19.4	8.9	2.17
0.2	21.7	10.2	2.12
0.1	28.6	14.7	1.94
		Average	2.10

Table 3. Statistics of attenuation ratios, May 1991. The CCIR attenuation ratio model value is 1.96 dB.

**With respect to clear air.*

Parameter	30-GHz signal	20-GHz signal
Beacon frequency band, GHz	27.5	20.0
Common antenna size, m	1.2	1.2
Antenna gain, dB	49.0	46.4
Nominal CONUS EIRP, dBW	16.0	16.0
Path loss, dB	215.0	212.0
RF loss, dB	2.0	1.8
Modulation loss, dB	—	3.2
Receive G/T, dB/K	17.6	15.1
C/N over 15 Hz, dB	33.4	30.9

Table 4. ACTS receive terminal link calculations.

experimenters. Rain climate zones without a prior Ka-band propagation database received special consideration during the award process; sites with an ongoing environmental sensing program employing radiosondes, weather radars, etc., were also given preferred consideration. Terminals will be placed at these seven sites: Vancouver, British Columbia, Canada; Fort Collins, Colorado; Fairbanks, Alaska; Clarksburg, Maryland; Las Cruces, New Mexico; Norman, Oklahoma, and Tampa, Florida.

References

[1] W. L. Stutzman and D. Chakraborty, "The OLYMPUS and ACTS Propagation Measurements Campaigns in the U.S.," *Proceedings 14th AIAA Conference*, March 22–26, 1992, Washington, D.C.

[2] W. L. Stutzman, et al., "Communications and Propagation Experiments Using the Olympus Spacecraft — Report on the First Year of Data Collection," *Virginia Tech Report EESATCOM 91-4*, submitted to JPL, October 1991. (Also published as SATCOM 202 report, available through the SATCOM Publications Office.)

[3] W. L. Stutzman, et al., "Communications and Propagation Experiments Using the Olympus Spacecraft — Analysis of Olympus Propagation Data for the Period January–May 1991," *Virginia Tech Report EESATCOM 92-5*, submitted to JPL, November 1992.

[4] F. Davarian, "ACTS Propagation Workshop — Opening Remarks," presentation to the *First ACTS Propagation Studies Workshop (APSWI)*, Santa Monica, California, November 28–29, 1989.

AMT Experiment Opportunities and Potential Applications

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Laura Randall, AMT External User Involvement
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During the 1980s, JPL's Mobile Satellite Experiment (MSAT-X) task was involved in the development and demonstration of system concepts and high-risk technologies to enable the introduction of commercial mobile satellite services at L-band. As a result of this technology development effort, a number of companies are now competing to build and launch a variety of L-band commercial mobile satellite systems.

In view of the inevitable congestion that will occur at L-band, NASA has directed JPL to focus on mobile communications at Ka-band (30/20 GHz). Ka-band's excellent potential for advanced applications is due to its ample bandwidth, which can support a large user base and a diversity of services. This higher frequency band also offers the possibility of using smaller and lighter components and antennas, making the spectrum particularly attractive for mobile and personal communication terminals. NASA's experimental Ka-band satellite, the Advanced Communications Technology Satellite (ACTS), has been designed with high-gain spot-beam antennas that further support small mobile and personal terminals.

JPL's experience with MSAT-X directly applies to the development of a mobile terminal for communications at Ka-band. However, there are very significant differences because of the many challenges arising from mobile operation in Ka-band. These challenges include a young technology with lossy RF components, significant rain attenuation, potentially large frequency uncertainties and large Doppler shifts.

The ACTS Mobile Terminal (AMT) task was initiated by NASA at JPL in June 1990 with a technology goal of overcoming these challenges and providing a testbed to explore the potential of Ka-band in supporting mobile users. The JPL AMT task has undertaken an intensive development activity to provide NASA in just two years with a terminal for experimentation with ACTS that is capable of transmitting and receiving signals via ACTS from a mobile platform. The objectives of the AMT task are to:

- Demonstrate speech/data transmission in the Ka-band land-mobile satellite communications channel.
- Develop the advanced, high-risk technologies and system concepts necessary for mobile satellite communications at Ka-band.
- Provide a platform for the realization of longer term goals of micro and personal terminal development.
- Characterize the communications channel and validate the efficacy of system concepts and technologies through experiments.

Since Ka-band has long-term potential in supporting a variety of user equipment concepts, JPL's approach has been to develop a testbed through which progressively more advanced technologies can evolve.

AMT Experiment Status

Beginning in late 1993, a series of experiments and demonstrations will be performed using ACTS and a demonstration vehicle equipped with a data acquisition system. Both voice and data links will be demonstrated in typical mobile and stationary environments. Basic technologies that enable Ka-band mobile communications will be demonstrated first, followed by enhancements to achieve improved system performance and efficiency.

During 1991, the AMT user involvement task began to actively assemble user groups with specific interests in using the AMT and ACTS for mobile communications experiments. The goals of this activity are to stimulate commercial use of AMT and ACTS technologies, to encourage the use of satellites for mobile communications and to support the competitiveness of the U.S. satellite communications industry. User groups also provide multiple sources for feedback on the usefulness and practicality of Ka-band mobile and micro services and can provide ideas for follow-on systems. Five user groups — in the areas of aeronautical, satellite news gathering, hybrid, telemedicine and government agency applications — were created to help plan and execute joint demonstrations and experiments, as well as to provide a forum for discussion and study of specific mobile applications of the AMT.

The AMT provides industry, academia and government organizations with a unique opportunity to test Ka-band mobile communications technologies in a variety of capacities and settings, enabling experimenters to become more familiar with new developments in satellite technology and applications for future uses. Companies or groups that are interested in attending an AMT demonstration or in performing an experiment are encouraged to contact Laura Randall at JPL.

Several levels of user participation are currently available for interested users:

- *AMT demonstrations.* Demonstrations allow interested parties to view the AMT in the field during testing. Follow-on meetings will be organized to answer specific user questions. Attendance at demonstrations does not require funding.
- *Specific demonstrations.* User-group-specific demonstrations can be organized at the request and with the joint participation of a user. Individual application demonstrations for satellite news gathering and telemedicine are already in the planning stages. For user involvement in specific demonstrations, application-specific equipment must be provided and funding committed to bring the user's financial contribution to at least 20% of the total cost.
- *Joint partnerships.* NASA/JPL will partner with industry to allow more in-depth research on specific applications for co-funding of 20–100% of the experiment cost. Proprietary issues and funding will be addressed through the JPL Technology Affiliates Program.
- *Manufacturers or service providers.* JPL's Technology Affiliates Program can also provide specific support to allow AMT technology to be manufactured or marketed. A prime example of this was JPL's support for the rapidly growing MSS market.

Participation in the AMT experiments can provide organizations with the opportunity to influence future uses and applications of the AMT and can provide a strategic market advantage through the early testing of Ka-band mobile technologies.

Current User Groups and Proposed Involvement

Aeronautical

In the last decade, the demand for high-quality, reliable voice and data satellite communications links between aircraft and ground — to improve air traffic management services and to meet the growing demand for passenger communications services — has grown dramatically. Improved communications for air traffic management services will result in increased passenger and crew safety and should reduce flight time and operational costs by optimizing the aircraft's flight path. Beyond these benefits, the airlines want enhanced passenger communications to maintain customer satisfaction and loyalty.

Currently, air traffic management and passenger communications services are offered terrestrially or at L-band using the Inmarsat I and II satellites. However, according to Dr. Keith Smith, speaking at the Inmarsat Worldwide Aeronautical Satellite Communications Conference (Montreal, Canada, July 13–15, 1992), Inmarsat believes that they will run out of spectrum at L-band for global aeronautical communications by the year 2000. As a result of this crowding, Inmarsat and private industry will need to have begun the transition to a new system by the turn of the century.

ACTS can be the testing ground for this new system. JPL has devised low bit rate and high bit rate aeronautical experiments to support aircraft–ground communications in Ka-band using ACTS and the AMT.

A low bit rate demonstration, currently being planned for early 1994, will establish a 4.8-kbps link between an aircraft and a ground station. The experiment will provide a baseline for government and industry to pursue advanced aeronautical communications systems at Ka-band. The main objectives are to:

- Establish and demonstrate a reliable duplex communications link between an aircraft and a fixed hub station via ACTS for the purpose of low bit rate voice and data transmission.
- Demonstrate and evaluate Ka-band MMIC antenna arrays for aeronautical mobile use.
- Characterize the Ka-band channel for aeronautical communications during aircraft cruise.

Electronically steered antennas are viewed as ideal candidates for an aeronautical communication system because of their conformal structure, but they have not been subjected to field experimentation to determine effects due to aircraft banking and changes in attitude angle during flight. Two different 20-GHz MMIC receive arrays will be provided through a cooperative effort with the U.S. Air Force's Rome Laboratory and the Air Force's Milstar Terminal Program Office. GE and Boeing, working under contract to the ACTS Program Office and the Air Force, will each deliver a small array suitable for the low bit rate aeronautical experiment.

A proposed high bit rate aeronautical experiment, for which planning began in 1992, would take place in late 1994. The proposed experiment would demonstrate high data rate compressed video (64 to 384 kbps) on a satellite link between an aircraft and a ground terminal. The experiment has the following objectives:

- Establish and demonstrate a reliable duplex communication link between the aircraft and a fixed hub station via ACTS for compressed video, voice, data and fax transmissions.
- Characterize the Ka-band channel for aeronautical communications during takeoff, cruise and landing.
- Evaluate aeronautical satellite communication system concepts common to both L-band and Ka-band system realization.
- Assess the performance of current video compression algorithms in a satellite communication link.
- Demonstrate and evaluate the use of mechanically steered antennas, and high G/T electronically steered antennas if available, for aeronautical mobile terminal use.

Several general aeronautical system concepts (common to both L-band and Ka-band aeronautical satellite communication systems) will be studied during this experiment. An in-depth study of effects during aircraft banking and changes in attitude angle during flight will assist in the future design of aeronautical communications systems. An overall system design will be recommended, including specifications for the aeronautical and ground communications terminal and the satellite design.

ACTS and the AMT will provide an opportunity to test new aeronautical satellite communications concepts, including characterization of the Ka-band mobile satellite communications channel, development of Ka-band hardware and a realistic appraisal of the capability of Ka-band technology to meet the challenge of providing future aeronautical communications services.

Satellite News Gathering

To date, nearly 30 organizations have expressed interest in AMT technologies for satellite news-gathering (SNG) applications, including major television networks, radio broadcasting stations, satellite service providers and SNG equipment manufacturers.

Currently, SNG vehicles have limited communications with their broadcast station while en route to a news event. They also cannot receive video from ongoing broadcasts — referred to as "net return" — which limits their ability to respond in real time to rapidly changing news events.

To meet some of these needs, an AMT satellite news gathering experiment would demonstrate several functions:

- Transmission of duplex voice, data and, possibly, compressed video in an SNG van while the van is en route to a field location and while it is at the field location.
- Interconnection of satellite equipment with current news gathering communications equipment.

In addition to field experiments, a demonstration of a modified AMT installed in an industry SNG truck is being planned for the 1994 National Association of Broadcasters Conference.

The AMT can provide new communications services en route to a news event and at the news site (net return). It can also provide duplex voice, computer file transfer, duplex group 3 fax, slow-scan image reception and compressed video reception. Major networks, TV and radio stations, equipment providers and satellite service providers are currently interested in demonstrations and individual experiments.

IDB Communications Group, in particular, is interested in holding an audio broadcast demonstration at the 1993 National Association of Broadcasters Conference in Dallas.

Hybrid Satellite and Cellular Experiment

Cellular and satellite communications will need to become increasingly integrated in the future to support user demands for better services and the trend toward personal communications systems. Advanced and high data rate information and communication technologies require the flexibility that a hybrid satellite/cellular system could provide. JPL has contacted numerous cellular service providers, equipment manufacturers and consultants in its attempt to design an experiment in order to better understand the processes involved in integrating satellite and terrestrial services. Experiment objectives are to:

- Demonstrate the performance of a dual-mode user terminal capable of sending and receiving both satellite- and cellular-based transmission of duplex voice and data.
- Demonstrate intelligent features of a dual-mode user terminal. The choice of medium will depend on cost, availability and capability for seamless call hand-off between systems.
- Demonstrate the interconnection of a satellite hub station and the cellular network to support such features as user location, seamless call hand-off between systems and call-quality monitoring.
- Characterize alternative interconnection schemes for a satellite hub station, including schemes that are functionally comparable to a cellular cell site, a mobile terminal switching office or some alternative structure.
- Examine and characterize the feasibility of various roles for satellites in a cellular system, including cellular traffic off-loading to a satellite during peak traffic capacity hours, cellular traffic off-loading to a satellite in regions of drop-out cellular coverage, and cellular traffic off-loading in suburban, rural and remote locations where cellular coverage does not currently exist.

ACTS and the AMT will provide an opportunity to test new aeronautical satellite communications concepts.

- Examine and characterize the feasibility of using satellites to aid in the network management of cellular systems, including visitor and home location registrars, back-haul links in remote or rugged terrain and interswitch communications in both routine and disaster scenarios.

The point of satellite/cellular experiments using the AMT is to demonstrate the interconnection of satellites and cellular systems and to demonstrate seamless call hand-offs between the systems.

Telemedicine

NASA's communications research can be used to provide enhanced health services in areas that do not have access to top-level medical facilities. The AMT can be used for telemedicine applications such as performing teleradiology and transmitting EKGs, EEGs and patient status reports, as well as for medical facilities in remote areas and paramedic voice communications in ambulances.

Practical medical applications of teleradiology include transmitting high-quality digital images at 64 kbps from remote locations to major medical centers for subspecialty consultation. A test of this application may be conducted using the AMT wherein transmitted digital images would be compared for quality and consistency to non-transmitted images at the remote site. Clinical factors would also be evaluated, such as timeliness of the diagnosis and maintenance of quality control from a remote location.

The AMT could also be used to subjectively and objectively assess the quality of voice and compressed digital voice for emergency vehicle operations in terms of bit error rate, system availability and reliability under varied weather conditions. In some areas, an integrated communications and navigational system might be very useful for mobile emergency and medical units.

US West, the University of Washington and the Pacific Advanced Communications Consortium have expressed interest in telemedicine applications. EMSAT, a Southern California–based emergency medical consortium, has submitted a proposal to experiment with the AMT for such applications. A telemedicine demonstration will likely be conducted while the AMT vehicle is running other tests in the Seattle, Washington, area. The objectives of this experiment will be to:

- Demonstrate transmission of slow-scan images, compressed video and duplex voice from a mobile clinic to a major treatment center or hospital for real-time diagnosis of patients in remote locations.
- Demonstrate interconnections of hospital equipment, such as computerized imaging scanners, with satellite terminal equipment.
- Transmit patient data, possibly including vehicle location information, from paramedics in the field to a hospital.
- Transmit hospital status information from the medical facility to paramedics in the field.

Government Agency Experiments

Mobile communications can play a very important role in day-to-day activities for many government agencies. Contacts with over 50 Federal and state governments have been established to encourage agencies to experiment with the AMT to explore its potential for meeting their needs.

Currently, the National Communications System (NCS) and the U.S. Army Space Technology and Research Organization are involved in land-mobile experiments. The NCS experiment will demonstrate secure mobile communications using the AMT and STU-IIIs. Testing will begin in late 1993 and last through 1995.

The Bureau of Land Management (BLM), U.S. Department of the Interior, has expressed interest in setting up a communications demonstration for fire suppression purposes. The BLM is considering using the AMT as a means to communicate with firejumpers who have been sent into fire areas in rural Alaska. In an operational scenario, small AMT-like terminals could be dropped by parachute into fire areas to provide immediate communications between firefighters and their commanders.

Another possibility involves demonstrating the utility of ACTS and AMT technology for future commercial low-Earth-orbit and geostationary satellite relays. JPL and NASA Johnson Space Center (JSC) would demonstrate direct communication links between the Space Shuttle, ACTS and JSC Mission Control to evaluate MMIC and Ka-band technologies (particularly the amplifiers and phased arrays) for application in a space environment.

Potential AMT Applications

The AMT Experiments Development task has also identified, but not thoroughly defined, other applications that could be demonstrated with the AMT. To pursue these ideas further, user groups need to be established or an individual experimenter identified.

Disaster-Mitigation Communications

AMT technology could provide temporary communications in disaster situations in which traditional communications channels are incapacitated or overloaded. Applications include reliable voice communications, remote monitoring of data, faxing graphics or text, surveying information and damage assessment. The AMT video capability could prove very useful for damage assessment and subsequent control activities.

A disaster relief demonstration could be accommodated while the AMT vehicle is in Washington state. Many of the requirements for an emergency communications system could overlap with rural telemedicine objectives. A joint medical applications and disaster relief experiment with law enforcement, medical and scientific assessment teams could also be coordinated to investigate how the AMT could address communications needs following an earthquake, fire, volcanic eruption or other disaster.

Maritime Communications

Portable voice, data, fax and real-time video capabilities could be provided by the AMT on pleasure or commercial craft or for U.S. Navy applications; however, a fair amount of these services are already provided by COMSAT, AMSC, Inmarsat and cellular communications firms.

Intelligent Vehicle Highway Systems

The AMT could be used by vehicle operators to efficiently navigate their routes by using GPS locators or by using the Automatic Vehicle Location satellite constellation. Voice and data could be used for maps, trip reservations and specific weather reports.

Rail Transportation

Real-time video could be sent to passenger trains for broadcast of current sports, entertainment and news events. In addition to passenger entertainment, AMT-type terminals could provide links for operational purposes. Also, there are potential monitoring applications for freight trains.

Mobile Office

ACTS could be used as a satellite switchboard to test the AMT's capability of providing ISDN service to vehicles. Vehicles could be driven to remote and rural areas and still have full office functioning capability. Industry may be interested in exploring a range of "information age" equipment and services to support sales and marketing staffs with large, international or remote territories.

Conclusion

Competition and alternative system concepts exist for each application discussed here. However, the AMT Experiments Development task provides a unique opportunity to test key parameters in the system tradeoffs that will be necessary for designing or selecting the optimal system.

With the launch of ACTS close to a year off, the opportunity still exists to explore new applications of AMT technologies. Applications for advanced mobile communications are limited only by our preconceived notions. JPL is interested in exploring all potential commercial or public welfare applications for the AMT.

The ACTS Mobile Terminal

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Throughout the 1980s, NASA and JPL were involved in the development and demonstration of system concepts and high-risk technologies to enable the introduction of commercial mobile satellite services at L-band. The final phase of that effort — technology transfer to U.S. industry — is now well under way. A number of U.S. and international companies are competing to build and place into service a variety of L-band commercial mobile satellite systems. In view of the inevitable congestion resulting from the limited bandwidths available at L-, C-, X- and Ku-bands, JPL has focused on Ka-band, which has wide bandwidth potential.

The key to the success of any future telecommunications system is its ability to provide many users with a diversity of services in a cost-effective manner. A cornerstone of system viability is the exploitation of economies of scale to reduce user equipment cost, which leads to a requirement for considerable system capacity to support a large pool of users and their varied demands. Ka-band will not only meet this capacity requirement but has the potential for supporting user equipment that is significantly smaller and possibly simpler than L-band equipment. Ka-band is therefore a good candidate for users who seek large capacities, service diversity and convenience. However, Ka-band poses significant challenges: It involves a young technology that has lossy RF components, significant rain attenuation, potentially large frequency uncertainties and large Doppler shifts in mobile applications. Thus, JPL's technology development goal has been to overcome these challenges with system architectures and components that are designed to exploit the potential benefits of migration to Ka-band; specifically, reduction in size and — whenever possible — reduction in complexity relative to L-band equipment. These gains and the large system capacities possible at Ka-band should lead to cost reductions in the utilization of mobile satellite communications.

Since Ka-band has a long-term potential to support a variety of user equipment concepts, JPL's approach has been to develop a Ka-band testbed through which progressively more advanced technologies can evolve. NASA has been pursuing the exploitation of Ka-band for applications using the Advanced Communications Technologies Satellite (ACTS), which possesses the high-gain spot-beam antennas required to support small mobile and personal terminals. ACTS, scheduled for launch in mid-1993, is thus a valuable "satellite of opportunity" to demonstrate advanced technologies. Concurrent with ACTS' availability, the first development target is the ACTS Mobile Terminal (AMT), a Ka-band technology testbed that will support long-term goals of micro and personal terminal development.

AMT Objectives and Approach

The AMT is a proof-of-concept breadboard designed to incorporate system and subsystem solutions devised to overcome the challenges of Ka-band land-mobile operation. An integral objective in the development of the terminal is the eventual commercial viability of AMT concepts and technologies. When the AMT is completed, a series of experiments and demonstrations using ACTS will be performed in 1993 and 1994. Both voice and data links (with rates automatically selected according to channel conditions) will be demonstrated in typical mobile and stationary environments. Basic technologies that enable Ka-band communications will be demonstrated first, followed by various enhancements to achieve improved system performance and efficiency. To aid in characterizing and understanding the Ka-band mobile channel and AMT operation in it, the demonstration vehicle will be equipped with a state-of-

the-art data acquisition system that will permit real-time as well as more thorough post-experiment analyses of Ka-band operations. The efficacy of the terminal's design and the technologies employed will be determined; channel-compensation schemes will be evaluated to assess the terminal's performance versus complexity. When these evaluations are completed, JPL will report its recommendations on mobile service operation at Ka-band.

Future experiments based on the AMT and/or its technology base are also being explored, with the aim of performing as many of them as possible in cooperation with industry. (*See the related article in this issue. —Ed.*)

System Architecture and Operation

Studies focusing on K-/Ka-band have explored system architectures and multiple-access schemes that can form the basis for a viable mobile and personal satellite communication system [1–4]. It has been shown that for CONUS coverage a geosynchronous satellite would be most practical, with the system typically taking the form depicted in Figure 1 — the AMT experimental setup. A fixed station communicates through the satellite with a large number of mobile or personal users scattered over CONUS. To alleviate the EIRP burden on the user terminal, satellite spot beams are used in covering CONUS. In principle, the satellite could be of the bent-pipe or processing type. However, since the technology for onboard processing to support a large mobile user base is still in its infancy, such technology could not be advocated without a complex tradeoff study. It has also been shown [1,3] that a nonprocessing, geosynchronous satellite in the bent-pipe mode could be utilized effectively with a combination of multiple-access schemes. Combining FDMA or CDMA with TDMA, capacities of 30,000 4.8-kbps channels have been predicted for a 6000-lb-class satellite. The bandwidth required is roughly 300 MHz.

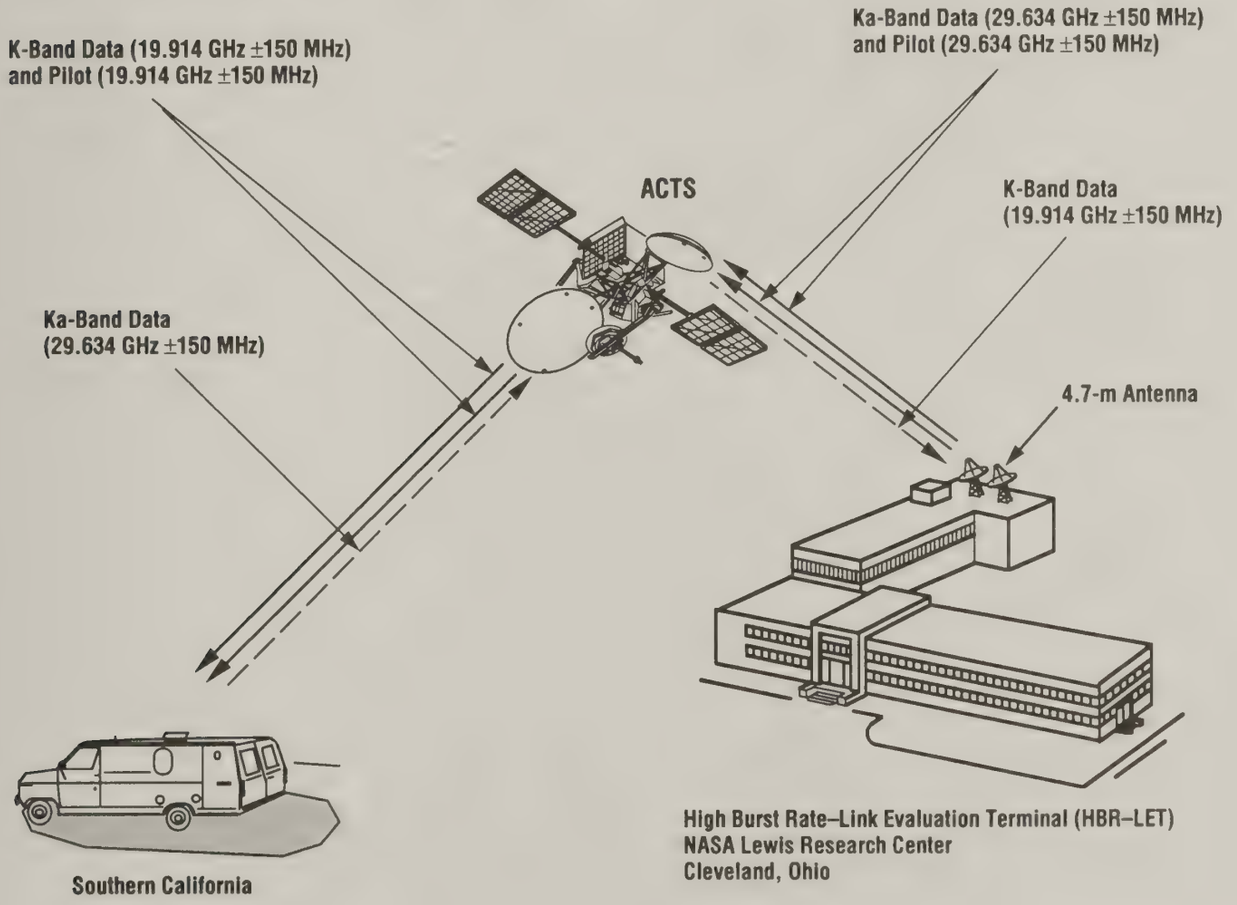

Figure 1. The AMT experimental setup.

To increase link availability and service continuity, the data rate on the AMT links can be reduced to compensate for rain attenuation.

Consistent with ACTS, AMT uplinks will be at 30 GHz and downlinks at 20 GHz, as shown in Figure 1. To be compatible with a planned mid-1993 satellite experiment, FDMA was selected for the base technology demonstration because of its lower risk. CDMA and TDMA techniques will be utilized in the follow-on enhancements.

In the FDMA architecture utilized for the AMT, an unmodulated pilot is transmitted from the fixed station to each user spot beam. The mobile terminal uses this pilot to aid antenna tracking and to measure rain attenuation, and as a frequency reference for Doppler correction and precompensation. For system efficiency, a pilot is transmitted only in the forward direction — i.e., from the fixed to the mobile terminal. Hence, for the AMT, there will be two signals in the forward direction: the pilot and the information (voice or data) link. In the return direction (mobile to fixed), only the information channel (commonly referred to as the data channel) is transmitted. The data rate is automatically selected (2.4, 4.8 or 9.6 kbps) depending on channel conditions. A separate higher rate of 64 kbps will also be supported, but only under certain link conditions.

The absence of a pilot on the return link necessitates a creative solution to the problem of Doppler compensation on that link. The return link Doppler due to car motion can be as high as 3 kHz, with a rate up to 250 Hz/sec. In addition, uncertainties in the various oscillators along the links can accumulate about 2 kHz of frequency offset. Thus, the Doppler and frequency uncertainties can be a large fraction of the data rates. In the AMT demonstration, the Doppler shift present on the pilot will be tracked at the mobile terminal, translated in frequency and used to precompensate (appropriately preshift) the data channel on the return link. This will result in a significant performance enhancement at the fixed terminal and a reduction in the guard bands that would otherwise be required.

Rain Compensation and the Communication Protocol

The communication protocols developed for the AMT are consistent with the networking protocol framework developed for MSAT-X [5,6] and were designed specifically to be efficient in the mobile satellite environment. The AMT links are classified as open-ended for voice or long data transfers such as fax, or closed-ended for short data transfers such as messages. Data transmission in either link type will be subject to acknowledgment and retransmission, as required, to ensure data integrity. The protocol constructs extend the generic L-band concepts to accommodate the additional requirements at Ka-band.

Operation at 20 and 30 GHz — particularly at 30 GHz — is susceptible to significant rain attenuation. To increase link availability and service continuity, the data rate on the AMT links can be reduced to compensate for any rain attenuation. Recent studies [7] have indicated that under worst-month conditions, system availability can be improved from as low as 90% to above 99% by reducing the data rate from 9.6 to 2.4 kbps.

The AMT rain-compensation algorithm (RCA) [7] and communication protocol [8] have undergone parallel development for maximum compatibility and efficiency in system operation. The RCA and the communication protocol enable proper initial selection of data rates as well as data-rate change "on the fly" (i.e., with about a quarter second of silence) during an existing link.

The RCA relies on channel-attenuation measurements at both link ends. The pilot is used at the mobile terminal and the satellite beacon(s) at the fixed terminal, with rain attenuation measured at each terminal. This is performed either in the IF downconverter's pilot receiver module in the case of the mobile terminal or in the beacon receiver at the fixed station. This information is then fed to the terminal controller, where it is processed by the RCA software. The RCA is used to perform data-rate selection or change initiation both at link setup and during an existing call (voice or data). Evaluations of tradeoffs have established that the most dependable and efficient data-rate control scheme is the one wherein a joint, conflict-free procedure for rate determination is used. Basically, the terminal that initiates a call, or that senses the onset of

attenuation during an existing call, transmits a request (appropriate packet) containing its information to the other terminal. The latter uses its own local information and the information it received to determine the final data rate; it then relays that information to the first terminal. During an existing voice call, the control packets exchanged are appropriately imbedded in the compressed voice in a manner that virtually eliminates any impact on the users [8]. The challenges in the design of the protocol have been to maintain sufficient robustness of the data-control procedure despite the possible presence of vegetative shadowing and to achieve responsiveness to rain dynamics while minimizing overhead, delay and implementation complexity [8].

Mobile and Fixed Terminal Design

Figure 2, which shows a block diagram of the mobile terminal, identifies subsystems as elements of two broad divisions of the AMT: the baseband and microwave processors. The baseband processor consists of a speech codec; a modem and terminal controller, and a data acquisition system (DAS). The elements of the microwave processor are the IF up- and downconverters (the first stage of upconversion and the second stage of downconversion), the RF up- and downconverters (the second stage of upconversion and the first stage of downconversion), the antenna controller and the antenna. The primary reason for the split into IF and RF modules is to enable the interface to the ground station RF equipment at the fixed site.

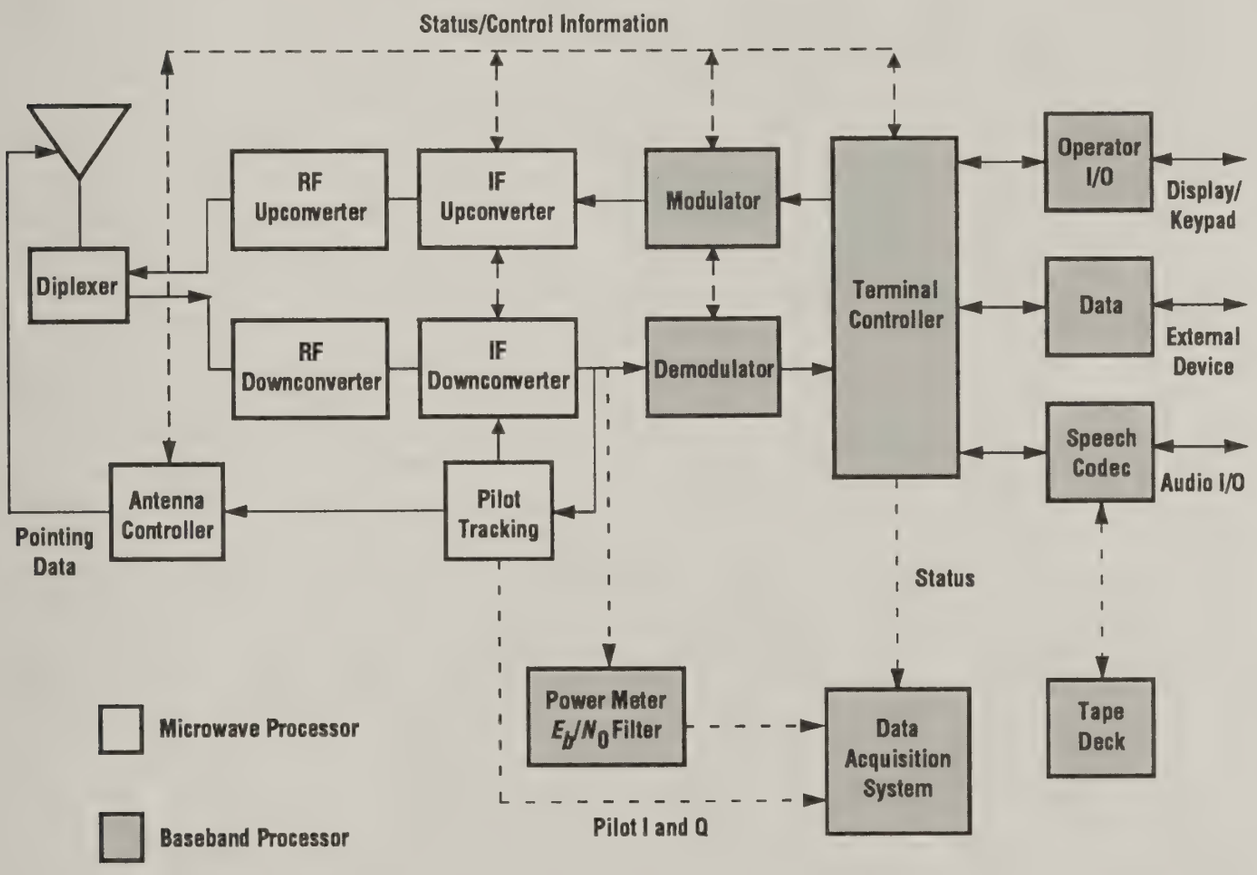

Figure 2. The mobile terminal.

Figure 3 shows a block diagram for the fixed terminal. The baseband processor is identical to that of the mobile terminal except that the ground station RF equipment is used instead of the mobile terminal's RF converter and vehicle antenna system.

Baseband Processor

The terminal controller (TC) is the brain of the AMT. It contains the algorithms that translate the communications protocol into operational procedures and interfaces among the terminal subsystems; it also contains and executes the RCA routines. The TC has control over IF and RF electronics operation; maintains high-level control over the antenna platform, and provides the user with a system-monitoring capability. It also supports an interface to the DAS and will support test functions required during experimentation, such as bit-stream generation, correlation and bit-error counting.

The speech codec converts input analog speech signals to a compressed digital representation at data rates of 2.4, 4.8 or 9.6 kbps, with monotonically improving voice quality. The 2.4-kbps compression algorithm is the U.S. Government standard LPC-10; the 4.8-kbps algorithm is the proposed CELP Government standard, and an MRELP algorithm has been adopted at 9.6 kbps. The latter may be changed to the digital cellular standard. Data-rate switches will be performed on command from the TC based on RCA information or on user command. Data-rate switching will normally occur "on the fly" with no user intervention

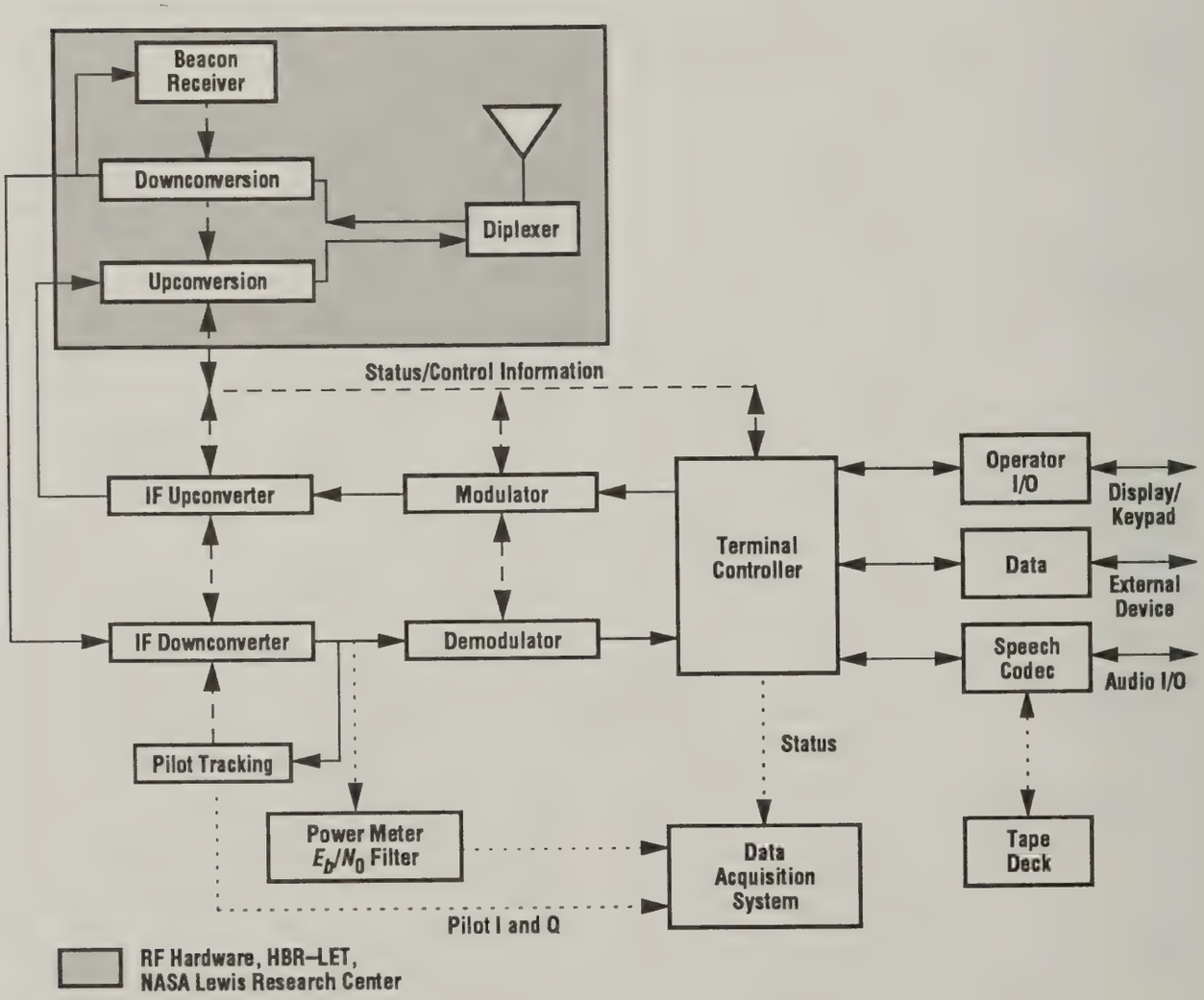

Figure 3. The fixed terminal.

and will have minimal impact on the continuity of the link. The codec will also contain special design features to make its operation robust in the mobile satellite environment, with its shadowing-induced outages. Finally, the codec will be capable of interfacing with the Public Switched Telephone Network.

The baseline AMT modem will implement a simple but robust DPSK scheme with rate 1/2 convolutional coding and interleaving so as to minimize the impact of ACTS' phase noise on modulation scheme performance. The modem has a bit-error rate of 10^{-3} at an E_b/N_0 of 7 dB in AWGN, including modem implementation losses. Half a dB of performance degradation due to ±4.5 kHz combined frequency offsets on the links through ACTS could be encountered. Additionally, up to 1.5 dB of degradation due to ACTS' phase noise could be experienced. Alternate modulation schemes such as "pseudo-coherent" BPSK, wherein link synchronization information is imbedded into the data channel, will be explored to investigate possible E_b/N_0 performance gains. In addition to the data rates of 2.4, 4.8 and 9.6 kbps, the modem will be designed to handle up to 64 kbps for a possible demonstration of slow scan (10 frames/sec) compressed video on the forward link. Essential to the modem design is a built-in robustness to deep, short-term shadowing. The modem will "free-wheel" — that is, it will not lose synchronization from signal outages caused by roadside trees. The modem is also being designed to handle the possible frequency offsets due to oscillator uncertainties and drifts along the link. Any residual Doppler at the mobile terminal that is not corrected through pilot tracking or at the fixed terminal (after precompensation) will be estimated and corrected in the modem's Doppler-estimation circuitry.

The DAS will perform continuous measurement and recording of a wide array of propagation, communication link and terminal parameters (e.g., pilot and data signal conditions, vehicle velocity and heading, noise levels and antenna direction). The DAS will also provide real-time displays of these parameters to aid experimenters in the field.

Microwave Processor

The critical Ka-band technology item in the microwave processor is the vehicle antenna. Two types of antennas are under development: a "passive" elliptical reflector to be used in conjunction with a separate HPA, and an "active" array with integrated MMIC HPAs and LNAs. Each type of antenna has distinct advantages. The reflector is simpler and less risky but requires a separate power amplifier, which could be an expensive or bulky item — not attractive characteristics in a commercial terminal. The active array, despite being more complex and risky to develop, exploits MMIC technology to overcome the losses in the Ka-band hardware and obviates the need for a potentially expensive power amplifier. The integration of the amplifiers also leads to a smaller, more conformal antenna assembly. With the potential mass market that Ka-band can support, the active array holds the promise of high performance at low cost. It will have a minimum EIRP of 22 dBW, G/T of –8 dB/K and bandwidth of 300 MHz. The reflector will reside inside an ellipsoidal water-repelling radome with a 9-in. outside diameter (at the base) and a maximum height of 3.5 in.

The antenna pointing system enables the antenna to track the satellite for all normal vehicle maneuvers. Both the antennas will be mated to a simple yet robust mechanical steering system. A scheme wherein the antenna will be smoothly dithered about its boresight by about a degree at a rate of 2 Hz will be used. The pilot signal strength measured through this dithering process will be used to complement the inertial information derived from a simple turn-rate sensor. The combination will maintain the antenna's aim at the satellite even if the satellite is shadowed for up to 10 sec. This mechanical pointing scheme is one of the benefits of migration to Ka-band. The considerably smaller mass and higher gain achievable relative to L-band makes the mechanical dithering scheme feasible and obviates the need for additional RF components to support electronic pointing. The necessary processing will reside in the antenna controller, which will later become part of the TC.

Preceding (or following) the antenna, the RF upconverter (downconverter) will convert an IF around 3.373 GHz to (from) 30 (20) GHz for transmission (reception). The choice of the 3.373-GHz IF band is dictated by compatibility with the fixed-station RF hardware (Figure 3) to be used at NASA Lewis Research Center (LeRC) in Cleveland, Ohio,

during the demonstration. The RF upconverter will also provide the passive antenna with sufficient power on the transmit signal to complete the communications link.

The IF converter translates between the 3.373 GHz IF and the lower 70-MHz IF at the modem. A key function of the IF converter is pilot tracking and Doppler precompensation. The downconverted pilot is tracked in a phase-locked loop and used as a frequency reference in the mobile terminal. The tracked pilot is also processed in analog hardware and mixed with the upconverted data signal from the modem to preshift it to offset the Doppler on the return link. The IF converter provides the TC and antenna subsystem with pilot signal strength for the RCA and for antenna pointing operation, respectively. Finally, the pilot in-phase and quadrature components are provided to the DAS for link characterization.

The planned AMT experiments will combine system and subsystem performance characterization with propagation measurements.

Experimentation With ACTS

ACTS will be used in the microwave switch matrix (MSM) mode — that is, as a bent-pipe repeater — to connect the fixed (hub) station with the mobile unit. The uplinks will be at 29.634 GHz ±150 MHz and the downlinks at 19.914 GHz ±150 MHz. These bands coincide with the RF bands where ACTS will be configured in the MSM mode to support the transmission of 220 Mbps. To simulate a hub station at the fixed terminal, the RF hardware of the High Burst Rate–Link Evaluation Terminal (HBR–LET) located at LeRC will be mated with the AMT baseband and IF equipment, as depicted in Figure 3. The HBR–LET hardware will comprise the 4.7-m antenna and RF up- and downconversion electronics for the 3.373-GHz interface.

Initially, the mobile terminal will be located in Southern California to allow access to ACTS via its Los Angeles–San Diego (LA–SD) beam. In the forward link, ACTS will be commanded by the NASA Ground Station (NGS) at LeRC to receive signals from the satellite's fixed Cleveland beam and to route them to the transmit feeds of the LA–SD beam. This scanning beam will remain fixed over the LA–SD area for the duration of the experiment. Two signals — the data and the pilot — will be transmitted through the HBR–LET and will pass through the ACTS transponder. The effects of the limiter in ACTS' MSM mode will be taken into account to obtain the correct link performance. This is reflected in the link budget for the experiment, which also includes performance degradation allowances for ACTS' phase noise and frequency offsets. It is worth noting that to accurately emulate a practical land-mobile satellite link, the power transmitted from the fixed station will be backed off by about 27 dB relative to the nominal specification of the ACTS system (which was originally intended for high data rates). On the return link, ACTS is commanded by the NGS to receive signals on the LA–SD beam feed of the ACTS uplink scanning beam (kept fixed) and to translate these signals via one of the other transponders to the fixed station at LeRC in Cleveland.

The AMT will implement a data-rate change procedure to enhance link availability during rain. At the fixed terminal, uplink power control is also available. The measured rain attenuation of the Cleveland beam is obtained from ACTS' beacon receivers in the NGS. This input is used to control the drive level of the HBR–LET's TWT amplifiers. This uplink power control will be used to complement the data-rate change capability of the AMT to compensate for rain on the forward link. Since the mobile terminal is limited in power, compensation for rain attenuation on the return link will be accomplished solely by data-rate control. However, both the power control and data-rate changes performed on the forward and return links have to be effected in concert for proper system operation. This will be performed under the supervision of the RCA residing in the AMT's TC.

The planned AMT experiments will combine system and subsystem performance characterization with propagation measurements. Pilot-signal measurements are central to all propagation-related experiments. At the mobile terminal, both coherent and noncoherent measurements of the pilot will be recorded. Sampling rates will be chosen to significantly exceed any possible pilot frequency variation or spreading due to Doppler or channel scatterers (such as tree tops or branches). The pilot tracking loop is being designed for a nominal C/N_0 of 50 dB-Hz, but it will continue to track even if the C/N_0 falls below this level. Hence, in the absence of rain (98% of the time in Los Angeles), shadowing-induced fades of 15 dB would be measurable. (Using the full power specified for ACTS at the fixed station would increase this substantially.) The data or voice channel signal will be measured by means of a power meter as well as through a received signal quality estimate in the modem.

Conclusion

JPL is developing a K-/Ka-band mobile terminal and is planning a series of mobile experiments to explore the potential of K-/Ka-band to meet the needs of future mobile satellite services. Two major technical challenges have been identified: maintaining the link in a demanding propagation environment and developing the enabling Ka-band technologies. The first challenge requires developing data-rate and power-control algorithms to compensate for rain fading; designing a modem and transceiver capable of combating Doppler and frequency offsets while providing power efficiency and robustness to shadowing, and the development of high-performance, simple-to-implement pointing algorithms. The second technical challenge entails the development of low-cost, high-performance, reliable small antennas that will utilize Ka-band MMIC components and packaging techniques.

The land-mobile experiments using ACTS are scheduled to start in mid-1993. They will be centered around the goal of providing a more accurate characterization of the Ka-band channel and demonstrating its potential for mobile communications. Emphasis will be placed on assessing the efficacy of the system concepts, subsystem designs and technologies adopted for the AMT. These experiments should serve as a starting point for other micro and mobile terminal applications at Ka-band. It is hoped that AMT development and the availability of ACTS as an invaluable satellite of opportunity will lead to other experiments and demonstrations of advanced land-mobile terminal hardware; maritime and aeronautical systems; hybrid satellite- and land-based networks, and, eventually, true personal microterminals.

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